

**Defense R&D Canada
DRDC - Toronto**

DRDC Toronto CR 2002-053

**SHORT-TERM AND
LONG-TERM COMFORT AND
EMG ASSOCIATED WITH SHOE
INSERTS**

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**SHORT-TERM AND LONG-TERM COMFORT AND EMG
ASSOCIATED WITH SHOE INSERTS**

By

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PWGSC Contract No. W7711-007680/001/TOR

on behalf of

DEFENSE R&D CANADA

as represented by

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21 June, 2002

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ABSTRACT

It was previously determined that military personnel would be more comfortable and suffer fewer injuries by using footwear inserts in their combat boots. However, different individuals require inserts with different characteristics. Since improved comfort is one of the main benefits of an appropriate insert, the goal of this study was to develop a simple comfort assessment method that would allow individuals to select the insert that was appropriate for them. By using a combination of short-term and long-term comfort assessments, a method was developed where subjects could reliably select the appropriate insert. To do this, subjects are required to assess the comfort of each available insert six times while trying them on in a random order. Their most comfortable insert in trials 3-6 will remain the most comfortable for them even after long-term wear, and is, therefore, the appropriate insert for them.

RÉSUMÉ

Il a été déterminé que les membres du personnel militaire seraient plus à l'aise et se blesseraient moins souvent s'ils plaçaient des supports podologiques dans leurs bottes de combat. Cependant, le type de support requis peut varier d'une personne à une autre. Étant donné qu'un des principaux avantages des supports est l'amélioration du confort, le but de l'étude était d'élaborer une méthode simple d'évaluation du confort qui permettrait à chacun de choisir le support qui lui convient. À partir d'une combinaison d'évaluations de confort à court terme et à long terme, une méthode a été élaborée pour permettre aux sujets de choisir le support approprié. Pour ce faire, les sujets doivent évaluer le confort de chaque support six fois en les essayant au hasard. Le support le plus confortable lors des essais 3 à 6 sera toujours le plus confortable même après avoir été porté à long terme et représente donc le support le plus approprié.

EXECUTIVE SUMMARY

Introduction and purpose

Initial results from previous studies with the Department of National Defense were positive suggesting that military personnel will be more comfortable and suffer fewer injuries if they use an insert that is appropriate for their characteristics. There are different methods to select or assign the appropriate insert. One is to use the methodology from the first study and assign an insert based on several measurements of each individual. However, this is very time consuming and at this point, there is simply not enough information to assign inserts appropriately to all individuals. Another is to use comfort as the selection criteria, which proved to be successful in the second study. However, it is currently unknown how repeatable current footwear comfort assessments are and if a short-term comfort rating relates to long-term comfort. Additionally it is desirable to determine if comfort can be related to a more objective measurement such as muscle activity. Such a relationship would help provide a functional explanation for differences in comfort ratings. It may also provide an objective measure that could potentially be implemented in future footwear assessments. Therefore, the purposes of this investigation were:

- to develop reliable methods for comfort assessment of specific shoe/insert situations and
- to determine if EMG can be used to assess comfort objectively for a specific situation.

Method

This study consisted of three aspects: short-term comfort assessments, long-term comfort assessments and quantification of muscle activity using EMG results. Twenty-two subjects assessed short-term comfort of three different insert conditions (soft, hard, viscous) after walking on a treadmill. Comfort was assessed using a visual analogue scale, several repeat measurements and a control insert. Long-term comfort was assessed after subjects wore the insert for a minimum of five consecutive hours on two consecutive days. EMG activity of the biceps femoris, rectus femoris, gastrocnemius medialis, tibialis anterior and peroneus longus muscles was collected for all trials.

Results and Discussion

Subjects were able to quantify comfort for different footwear inserts. Using six repeat trials and averaging the ratings from trials 3-6, repeatable and reliable comfort ratings for footwear inserts were obtained within 0.5 comfort points. This "testing" procedure lasted approximately one hour for four different insert conditions. Furthermore, using this methodology, the short-term comfort ratings were highly correlated to the long-term comfort assessments. Some subjects were less repeatable than others, which did not influence individual comfort ratings. However, it is recommended to remove the assessments from subjects with a low repeatability if an average comfort rating for particular footwear is required.

Changes in inserts produced no consistent effects with respect to muscle activity. The majority of subjects showed no changes in mean EMG frequency and/or intensity as a function of changes in inserts. However, some subjects showed changes in the EMG output. Changes in muscle activity were expected when the inserts attempted to change the path of motion. However, these changes may have been small and the tested inserts may all have been acceptable, providing only small differences in functional responses. Thus, assessment of EMG activity may not be appropriate for assessing the functionality of inserts/orthotics/shoes with small changes.

Based on the results of this study one can conclude that comfort assessment is the best approach in selecting an adequate footwear condition. It is repeatable, not time consuming and (based on results from previous studies) seems to be related to functional aspects.

SOMMAIRE

Introduction et objet

Les premiers résultats d'études menées au ministère de la Défense nationale ont permis de déterminer que les membres du personnel militaire seraient plus à l'aise et se blesseraient moins souvent s'ils utilisaient des supports podologiques adaptés à leurs caractéristiques. Différentes méthodes peuvent être utilisées pour choisir ou prescrire le bon support. La méthode utilisée dans la première étude consiste à fournir un support conçu à partir de différentes mesures personnelles. Cette méthode prend cependant beaucoup de temps et on ne possède pas encore suffisamment de renseignements pour prescrire le support approprié à chaque personne. La méthode utilisée lors de la deuxième étude, qui s'est avérée concluante, consiste à utiliser le confort comme critère de sélection. Cependant, on ne connaît pas encore le degré de reproductibilité des évaluations de confort actuelles des chaussures et on ne sait pas si une cote du confort à court terme peut être appliquée au confort à long terme. De plus, il serait utile de déterminer si le confort peut être associé à une mesure plus objective comme l'activité musculaire. Un tel lien nous permettrait de fournir une explication fonctionnelle aux différences entre les cotes de confort et pourrait nous fournir une mesure objective pouvant être utilisée dans les évaluations futures de chaussures. La présente étude avait donc pour but :

- d'élaborer des méthodes fiables permettant d'évaluer le confort de différentes combinaisons chaussure/support;
- de déterminer s'il est possible d'utiliser des mesures électromyographiques (EMG) pour évaluer le confort de façon objective dans une situation donnée.

Méthode

L'étude comprend trois volets : évaluations du confort à court terme, évaluations du confort à long terme et calcul de l'activité musculaire à partir de mesures EMG. Vingt-deux sujets ont évalué le confort à court terme de trois différents types de supports (souples, rigides, gélatineux) après avoir marché sur un tapis roulant. Le confort a été évalué à l'aide d'une échelle visuelle analogique, de plusieurs répétitions de mesures et d'un support témoin. Le confort à long terme a été évalué après que les supports aient été portés deux jours de suite pendant au moins cinq heures consécutives. L'activité EMG des muscles biceps cruraux, droits antérieurs de la cuisse, gastrocnémiens internes, tibiaux antérieurs et péroniers longs a été mesurée pendant tous les essais.

Résultats et discussion

Les sujets ont pu coter le confort de différents supports podologiques. Des cotes de confort reproductibles et fiables pour supports podologiques en deça de 0,5 points de confort ont été obtenus en effectuant six essais et en calculant la moyenne des résultats des essais 3 à 6. Cette procédure « d'essai » a duré environ une heure pour quatre différents types de supports. Cette méthode a permis d'établir une corrélation élevée entre les cotes de confort à court terme et celles du confort à long terme. Les cotes de certains sujets étaient moins reproductibles que d'autres,

mais cela n'a pas influé sur les cotes de confort individuelles. Il est cependant recommandé de retirer les évaluations des sujets dont le taux de reproductibilité est faible pour obtenir la cote de confort moyenne d'une chaussure donnée.

Les changements de supports n'ont eu aucun effet marqué sur l'activité musculaire. Pour la majorité des sujets, la fréquence EMG moyenne et/ou l'intensité variaient très peu en changeant de support, mais les données EMG variaient pour certains sujets. Des changements dans l'activité musculaire avaient été anticipés pour les supports qui tentaient de modifier le trajet du mouvement, mais les différences dans les réponses fonctionnelles étaient minimales probablement parce qu'il y avait peu de changement et que les supports mis à l'essai étaient acceptables. L'évaluation de l'activité EMG peut donc ne pas convenir à l'évaluation de la fonctionnalité des supports/orthèses/chaussures modifiant peu le trajet du mouvement.

Les résultats de l'étude permettent de conclure que l'évaluation du confort est la méthode qui convient le mieux lorsque vient le temps de choisir une chaussure adéquate. Cette méthode est reproductible, prend peu de temps et (en fonction des résultats d'autres études) semble avoir un lien avec les aspects fonctionnels.

INTRODUCTION

The current study is the third phase of a long-term collaboration that began in 1997 between the Human Performance Laboratory and the Defense and Civil Institute of Environmental Medicine, Department of National Defense. The results of the first phase indicated that cases existed where certain groups of individuals with similar characteristics preferred similar footwear inserts. For example, subjects with high plantar foot sensitivity preferred soft and viscous inserts while subjects with low plantar foot sensitivity preferred hard and elastic inserts. Also, individuals with poor skeletal alignment preferred soft and viscous inserts. Based on these results, it was hypothesized that individuals who used footwear appropriate to their characteristics would have increased performance and fewer injuries than individuals who were assigned generic footwear. This hypothesis was evaluated in a second phase.

The second phase consisted of on-site testing with 206 military personnel from Edmonton Garrison. Results indicated that all insert conditions were more comfortable than the military issued insert. Furthermore, when subjects were allowed to use an insert they preferred, they were less likely to suffer pain and fractures than if they used the military issued insert. There was no difference in performance (oxygen consumption) between wearing the selected or the issued insert. However, this result must be interpreted with caution due to a limited sample size. An additional result was that comfort could be improved for 90% of the individuals by allowing them to select from a group of only four different inserts.

The positive results from the first two phases suggest that military personnel will be more comfortable and suffer fewer injuries if they use an insert that is appropriate for their characteristics. There are different methods to select or assign the appropriate insert. One is to use the methodology from the first phase and assign an insert based on several measurements of each individual. However, this is very time consuming and at this point, there is simply not enough information to assign inserts appropriately to all individuals. Another is to use comfort as the selection criteria, which proved to be successful in the second phase. However, it is currently unknown how repeatable current footwear comfort assessments are and if a short-term comfort rating relates to long-term comfort. Additionally, it is desirable to determine if comfort can be related to a more objective measurement. For example, it has been speculated that comfort may be related to muscle activity (Nigg, 2001). Such a relationship would help provide a functional explanation for differences in comfort ratings. It may also provide an objective measure that could potentially be implemented in future footwear assessments.

Therefore, the purposes of this investigation were:

- to develop reliable methods for comfort assessment of specific shoe/insert situations and
- to determine if EMG can be used to assess comfort objectively for a specific situation.

LITERATURE REVIEW

Footwear comfort

Footwear comfort has been shown to be associated with plantar pressure distribution (Chen et al., 1994; Hennig et al., 2000), foot and leg structure (Hawes et al., 1994), foot sensitivity (Mündermann et al., 2001) and overuse injuries (Volpin et al., 1989; Ballas et al., 1997; Richie & Olson 1993). More recently, footwear comfort has been speculated to be associated with biomechanical characteristics such as lower extremity kinematics, kinetics and muscle activity (Nigg et al., 1999; Nigg, 2001), which could in turn influence fatigue and performance.

Nigg (2001) suggested that if footwear comfort affects muscle activation, wearing comfortable shoes should require lower oxygen consumption than wearing uncomfortable shoes. He was able to show that this was indeed true for a group of ten subjects. Although muscle activity was not measured directly, the implied conclusion was that the muscle activity was greater when wearing the uncomfortable shoes.

Comfort Repeatability

It has been suggested that comfort cannot be measured directly (Cavanagh, 1980; Slater, 1985). However, comfort has been and continues to be used extensively in footwear evaluations (e.g. Chen et al., 1994; Milani et al., 1995; Hennig et al., 1996; Miller et al., 1999; Mündermann et al., 2001), despite a lack of understanding about the reliability of comfort as a measure to assess footwear. In fact, only two recent studies (Miller et al., 1999; Mündermann et al., 2001) reported on the repeatability of their comfort measures. Both studies found low correlation coefficients of comfort ratings for repeated conditions, which may be due to some of the following factors.

The rating that an individual assigns to a situation is dependent on experience they have had with similar situations in the past (Nunnally, 1978). Thus, when trying to rate the comfort of a footwear insert, subjects must call upon previous experience they have with different footwear. Mündermann et al. (in press) were able to show that comfort ratings of shoe inserts differed significantly depending on what condition preceded the comfort assessment. In order to eliminate this bias, they suggest wearing a control condition before evaluating each experimental situation.

In the past, most footwear comfort has been assessed using ordinal scales (Chen et al., 1994; Milani et al., 1995; Hennig et al., 1996; Miller et al., 1999). Ordinal comfort scales, or ranking scales order objects from "least" to "most", without indicating, in an absolute sense, how comfortable the object is (Nunnally, 1978). One particular kind of ordinal scale is where subjects rate various objects on a seven or fifteen point scale ranging from lowest to highest. For example, the Borg-scale was initially developed to assess perceived exertion (Borg, 1982) and has been used to assess footwear comfort (Milani et al., 1995; Hennig et al., 1996; Miller et al., 1999). This scale can be used to determine relative differences between conditions. However, small differences cannot be detected due to the discreet ratings. Ordinal data also requires the use of non-parametric statistical methods in its analysis. The discrete sets of answers with ordinal

data can introduce errors to correlations between comfort and other biomechanical variables that are measured on continuous scales (Mündermann et al., in press)

Visual analogue scales (VASs) have been used and shown to be reliable in assessing subjective pain (Price et al., 1983; Gramling et al., 1992). VAS responses are easy to obtain and require little instruction. The sensitivity and reliability of VASs are influenced by the wording used to anchor the endpoints, the length of the VAS and other factors (Scott et al., 1976; Eich et al., 1985; Steven et al., 1980). VASs that are between 100 and 150 mm in length have been shown to possess the greatest sensitivity and are the least vulnerable to biases in ratings (Steven et al., 1980). It has also been suggested that the reliability of VASs can be increased by including specific instructions for subjects (Price et al., 1983).

Mündermann et al. (in press) used a 150 mm VAS with written instructions and repeat measurements to test footwear comfort for four different inserts. They found significant differences in comfort ratings between the insert conditions. Furthermore, the correlation between repeated comfort ratings was quite high (0.799). They concluded that VASs provide a reliable measure to assess footwear comfort provided that a control condition is included and that the average comfort rating of sessions (trials) four to six is used as a true comfort rating.

METHODS

This study consisted of three aspects: short-term comfort assessments, long-term comfort assessments and quantification of muscle activity using electromyography. Twenty-two subjects tested four different insert conditions.

Subjects

Twenty-two volunteers (18 males, 4 females; age 26.8 ± 4.0 yrs; height 179.1 ± 4.1 cm; weight 78.5 ± 9.1 kg) gave informed consent and participated in the study. All subjects were free from any lower extremity pain or injury at the time of testing.

Inserts

Three inserts from the initial phase of the Department of Defense insert study were evaluated (Figure 1). The inserts were initially designed to fit in the Mark III combat boots and are defined as hard, soft and viscous as described in Table 1. The top layer of the three inserts had the same color and texture, thus the subjects were not able to visually distinguish between the manipulated conditions. All inserts were used with a standard running shoe (Adidas Hoshi). The insert provided with the running shoe was used as the control insert for a baseline comparison.

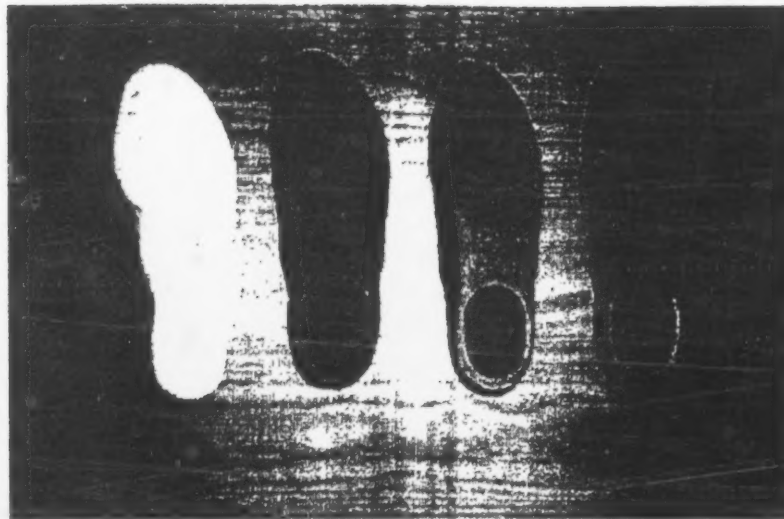


Figure 1. Photograph of the tested inserts. The inserts are the same inserts as used in the first phase of the ongoing study. The control insert (far left) was the insert provided with the test shoes (Adidas Hoshi).

Table 1. Properties of the different inserts tested.

Insert	Heel		Forefoot	
	Material	Shore C	Material	Shore C
Control	Medium		Medium	
Hard	Hard	65.3	Hard	65.3
Soft	Soft	39.3	Soft	39.3
Viscous	Viscous gel	49.3	Soft	39.3

Short-term Comfort

Data were collected in a single one and a half hour session. Prior to testing, subjects were instructed in regards to the testing protocol and the comfort assessment. Subjects were required to assess each insert six consecutive times using a randomized protocol (Figure 2). Each trial consisted of walking on a treadmill (0% grade) for approximately one minute at 1.52 m/sec. Subjects were instructed that the first, third, fifth, etc. testing condition was the control condition, but were unaware of which insert condition was being tested. At the end of the trial, subjects were required to provide a comfort assessment for the insert worn.

Short-term comfort						
Set 1	control	soft	control	viscous	control	hard
Set 2	control	viscous	control	soft	control	hard
Set 3	control	soft	control	hard	control	viscous
Set 4	control	hard	control	viscous	control	soft
Set 5	control	soft	control	hard	control	viscous
Set 6	control	soft	control	hard	control	viscous

Figure 2. Sample test protocol used for the short-term comfort assessment by subject 21. Test conditions were randomized for all subjects so different subjects would undergo different protocols.

The comfort measure consisted of a 150 mm visual analogue scale with the left end labeled "not comfortable at all" (0 comfort points) and the right end labeled "most comfortable condition imaginable" (15 comfort points) (Mündermann et al., in press). Since many aspects of footwear may influence comfort, specific comfort ratings were included for forefoot and heel cushioning. Written instructions (Figure 3) were given to subjects to eliminate differences in assessments and between subjects that could result from inconsistent oral instructions. The first comfort rating of the control condition in each set was used for further analysis.

There are several aspects of shoes which we are interested in measuring:

<i>overall comfort</i>	overall impression of the shoe
<i>heel cushioning</i>	softness/hardness of the insole in the heel region
<i>forefoot cushioning</i>	softness/hardness of the insole in the forefoot region

There are scales for measuring each of these aspects of the shoes. Although some shoe aspects may be equally comfortable we would like you to judge the aspects independently. Please mark the line to indicate the relative comfort of a specific shoe condition: the further to the right, the more comfortable the shoe. Similarly, mark the other lines to indicate the comfort of the specific shoe aspects.

Figure 3. Written instructions given to the subjects before testing.

Long-term Comfort

Long-term comfort was assessed after the subjects wore each insert a minimum of five consecutive hours on two consecutive days. The first insert was given to the subject at the end of the short-term tests. After wearing the insert for the specified time, the subject returned to the laboratory for the long-term comfort assessment. A protocol similar to the short-term comfort was followed with each subject walking for approximately one minute on a treadmill at 1.52 m/s. Since the subjects were now familiar with the insert, the long-term assessment consisted of three

repeat measures. After the long-term comfort was assessed for the first insert, the subject was given the second insert. Two pre-test comfort ratings were obtained for the second insert before the subject left for the second long-term wear period. This protocol was then repeated again for the final insert (Figure 4). Each long-term comfort assessment was completed in approximately one half hour. The inserts were assigned to the subjects in a random order.

Long-term comfort										
Set 1	control	viscous	control	viscous	control	viscous	control	hard	control	hard
Set 2	control	hard	control	hard	control	hard	control	soft	control	soft
Set 3	control	soft	control	soft	control	soft				

Figure 4. Sample test protocol used for the short-term comfort assessment by subject 21. Each set of measurements was performed after wearing the insert for five hours a day on two consecutive days. Test conditions were randomized for all subjects so different subjects would undergo different protocols.

Electromyography

During each trial, electromyography (EMG) data were collected during the last 10 seconds of each condition. Muscular activity was collected on five muscles of the left leg (Figure 5). These were rectus femoris, biceps femoris, tibialis anterior, peroneus longus, and gastrocnemius medialis. Prior to applying the Ag/AgCl bipolar electrodes (novotrode 20; interelectrode spacing 2.2 cm) the skin was prepared by shaving any hair over the contact area and cleaning with isopropyl alcohol wipes to reduce the resistance between skin and electrode. Leads connecting the electrodes to the collection unit were secured using adhesive bandages, the collection unit was secured to the handle bar of the treadmill in use. The data were sampled at 2400 Hz.

All EMG recordings were transformed using a set of 11 non-linearly scaled wavelets as filters. The result was an intensity pattern of the EMG where the x-axis represents normalized time and the y-axis the wavelets (the frequency of the wavelet). The gray scale indicated the intensity of each wavelet at every time point (von Tscharnier, 2001). Eight steps of EMG were averaged per condition and compared between inserts when subjects had a difference in comfort rating of at least two comfort points.

Statistical Analysis

Short-term comfort ratings of the different conditions were compared using a repeated measures analysis of variance (ANOVA) and students t-tests. Pearson's correlation coefficients were calculated between short-term and long-term comfort. Comparisons of EMG intensity and frequency between comfortable and uncomfortable conditions were performed using paired students t-tests. The level of significance for all analyses was set at $\alpha < 0.05$.

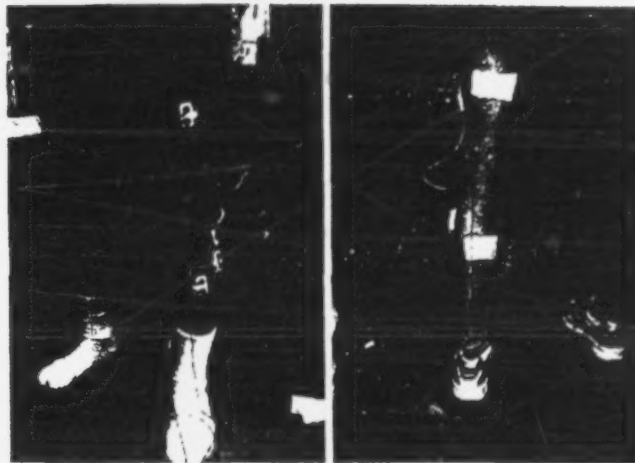


Figure 5. Photographs of the EMG electrodes placed on the lower extremity muscles.

RESULTS

Overall Short-term Comfort

When combining all trials of all subjects, there were significant differences in the short-term comfort ratings between the different inserts. The subjects rated the control insert as the most comfortable, the soft insert as the second most comfortable and the hard insert as the least comfortable (Figure 6). This result indicates that on average, subjects were able to identify comfort differences associated with different shoe inserts. This is similar to the results found from previous studies. Also similar to previous investigations is the fact that soft inserts were rated more comfortable than hard inserts. The control insert had the highest average comfort rating which may be due to the fact that it was specifically designed for the shoes used in this investigation. The comparison (soft, hard and viscous) inserts were the same inserts that were used in the first study. They were originally designed to fit into the Mark III combat boot and it may be that their fit in the running shoes was not ideal. However, the data showed that subjects were able to differentiate between the inserts, thus allowing further analysis of the comfort methodology.

Specific comfort ratings of the heel and forefoot cushioning showed similar results to the overall comfort ratings (Figure 7). The control insert received the highest ratings while the hard insert received the lowest ratings for both heel and forefoot cushioning. Thus, similar to the overall comfort, subjects were able to identify differences between the inserts with respect to specific aspects of the inserts.

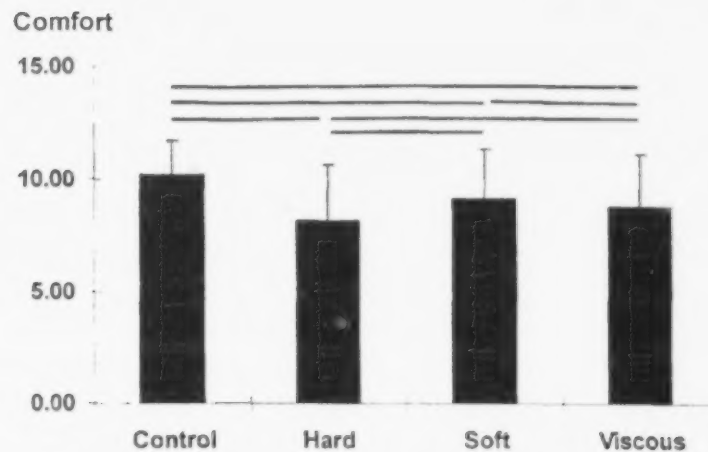


Figure 6. Overall short-term comfort rating for all subjects and all different insert conditions. Bars across indicate a significant difference ($\alpha < 0.05$).

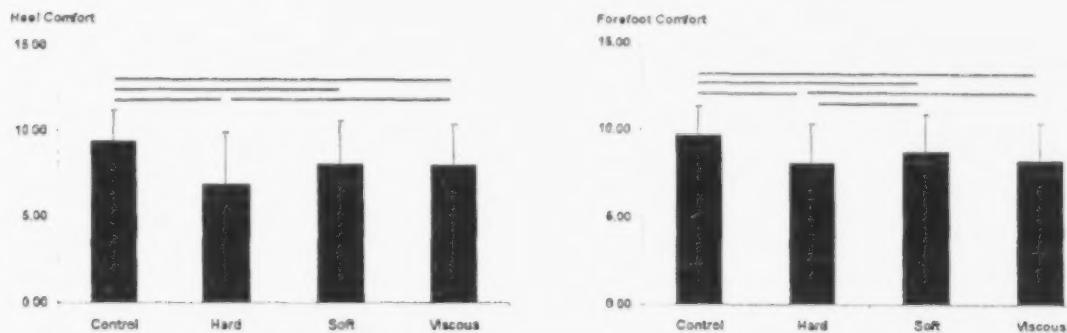


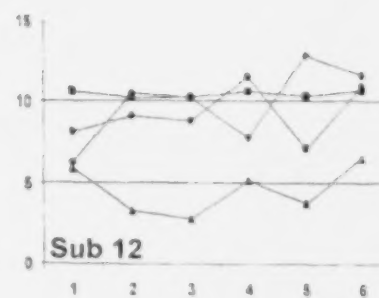
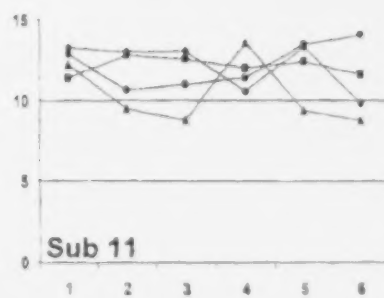
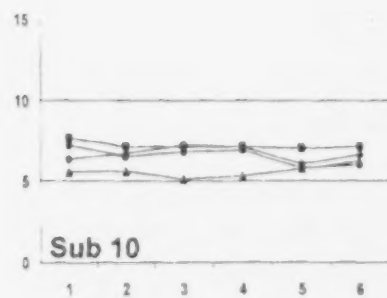
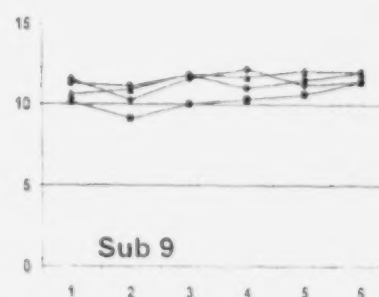
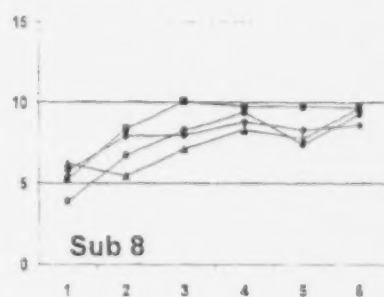
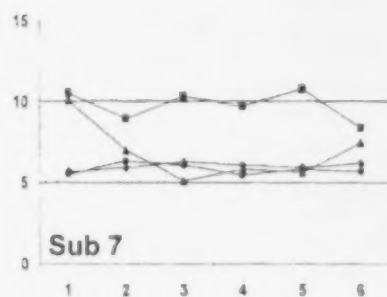
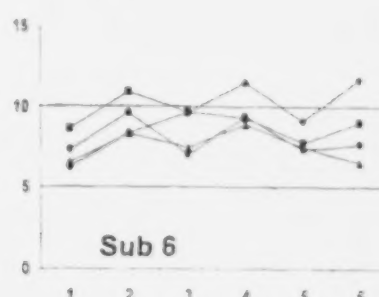
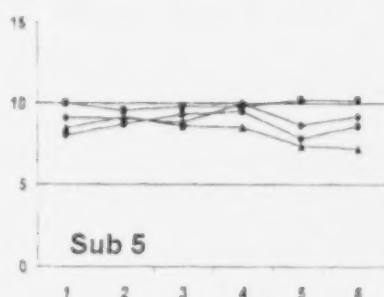
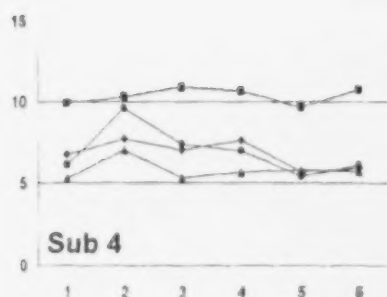
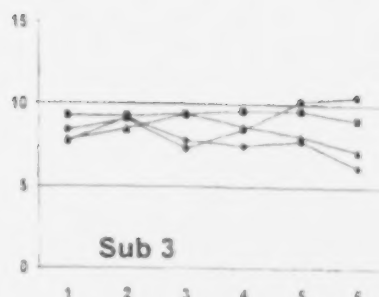
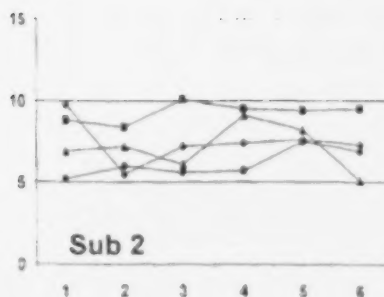
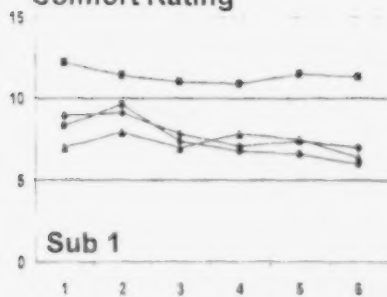
Figure 7. Overall short-term comfort aspects of the heel and forefoot for all subjects and insert conditions. Bars across indicate a significant difference ($\alpha < 0.05$).

Individual Comfort

The short-term comfort assessments for all 22 subjects showed some interesting results (Figure 8):

- Some subjects used a wide range of comfort ratings (e.g. subjects 4, 19) while others used a very narrow range (e.g. subjects 15, 20).
- Some subjects required additional time or an increased number of evaluations to reach a stable comfort rating (e.g. subjects 8, 16) while others were able to do it very quickly (e.g. subjects 5, 22).
- Some subjects were highly repeatable in their comfort ratings (e.g. subjects 10, 13) while others were not (subjects 14, 18).

Comfort Rating



Session

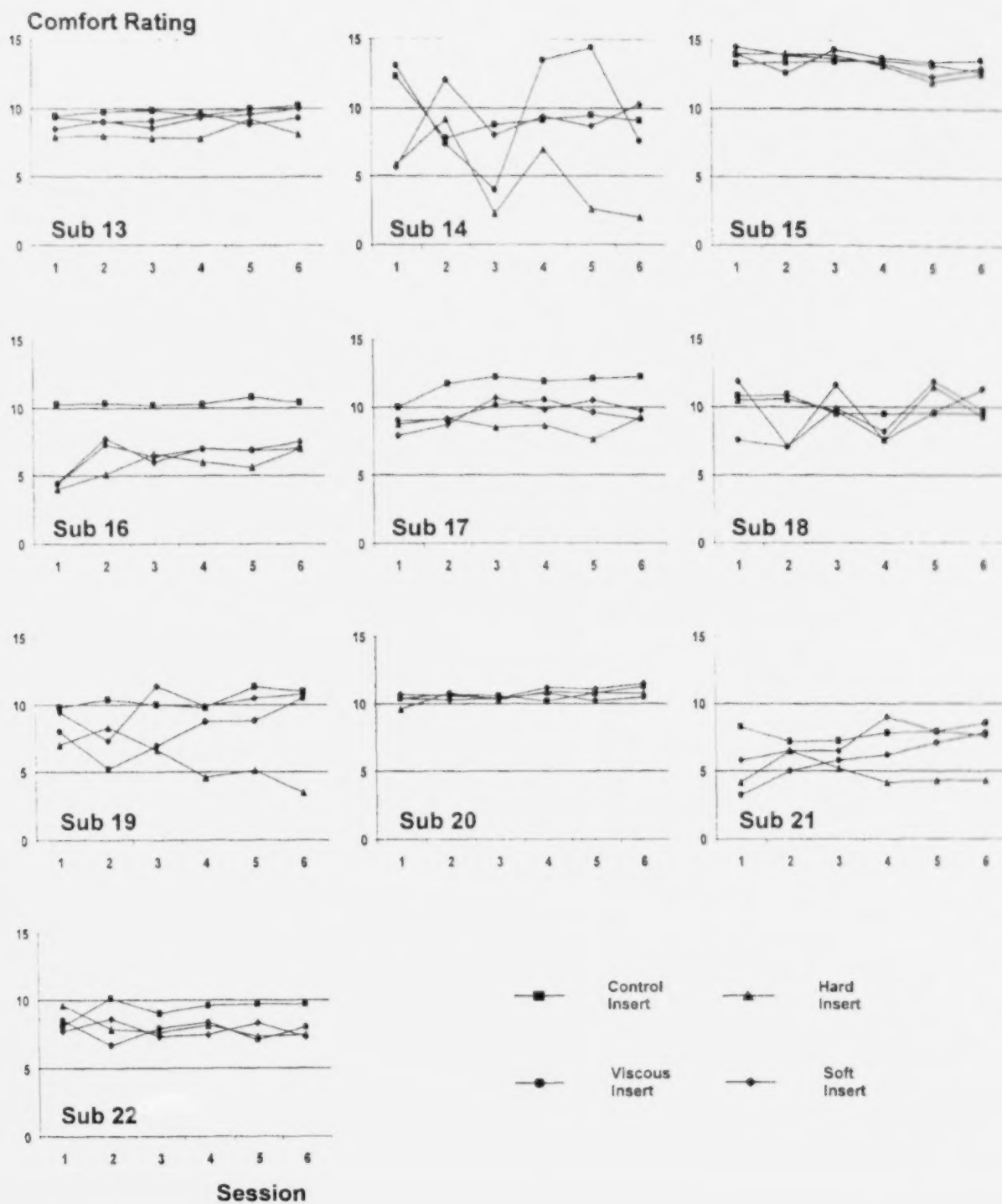


Figure 8. Short-term comfort ratings for all subjects and all inserts.

It may be that the subjects who used a very narrow range of comfort ratings cannot easily differentiate between the different insert characteristics. They may have low sensitivity on the plantar surface of their feet. Alternatively, they may be individuals whose general nature influences their perceptions. For example, subject 15 rated all inserts as very comfortable despite the fact that they ranged from soft to hard. Subject 15 may have a very positive overall attitude that influences his insert comfort ratings.

Several subjects required an "accustomization" period to become familiar with the different inserts before they were able to assess them repeatably. For example, the initial comfort assessments for subject 8 differed substantially from his final comfort assessments. When looking at the comfort ratings of subject 8, it is clear that the subject was repeatable in the latter half of his assessments despite having different comfort ratings from the initial assessments. Some subjects had a very low repeatability throughout the entire set of comfort ratings. It is speculated that these individuals will not reach a stable comfort rating regardless of the number of repetitions. Therefore, it is not necessary to collect more than six evaluations.

Comfort Repeatability

On average, the difference in comfort ratings between two consecutive tests was highest between sessions one and two (Figure 9). After the initial rating, the variability in comfort ratings between consecutive evaluations decreased. Therefore, to reduce the variability in overall comfort ratings, it is recommended to exclude the initial rating from the average comfort ratings. The vast majority of comfort studies in the past have used a single comfort rating (e.g. Chen et al., 1994; Hennig et al., 1996). The current results suggest that the previous studies should be interpreted with caution, as their comfort ratings may not reflect true values.

The variability in the comfort ratings can also be improved by eliminating unrepeatable subjects from the overall calculations. For example, by removing the five least repeatable subjects (subjects 11, 12, 14, 18, 19), the differences in comfort ratings between repeat evaluations decreases substantially (Figure 10). The average difference between consecutive comfort ratings for all subjects is about 1.3 comfort points after excluding the first assessment. However, the average difference between consecutive comfort ratings for the 17 more repeatable subjects improves to about 1.0 comfort points after excluding the first assessment. Thus, if the goal of an investigation is to obtain an average comfort rating for a piece of footwear, it is recommended to remove the assessments from unrepeatable subjects. However, this is not necessary if the goal is to assess comfort on an individual basis, such as in this investigation.

Difference in Comfort Ratings

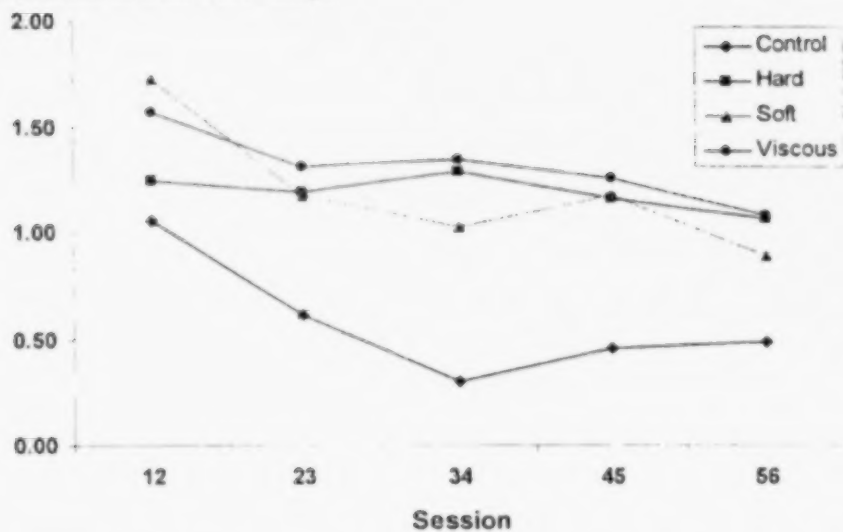


Figure 9. Differences in comfort ratings between two consecutive trials for the various tested inserts. Data are the average for all 22 subjects.

Difference in Comfort Ratings

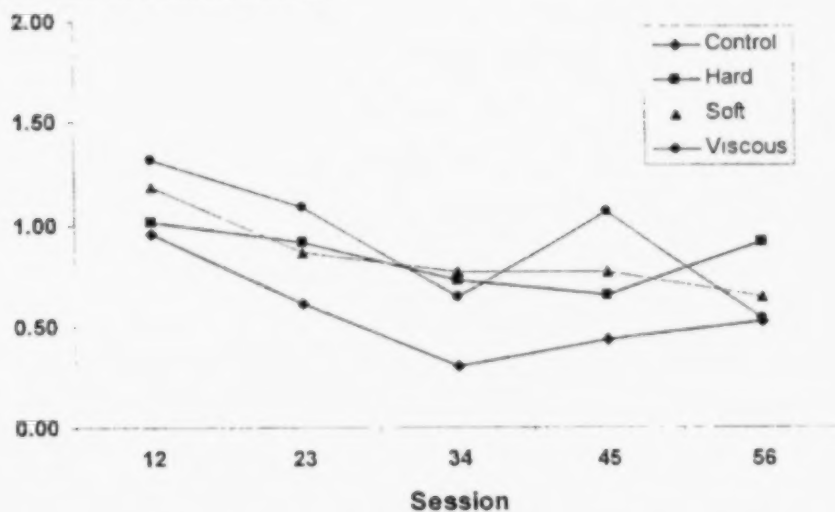


Figure 10. Differences in comfort ratings between two consecutive trials for the various tested inserts. Data are the average for the 17 repeatable subjects.

Short-Term Comfort

The "true" short-term comfort value of an insert for each individual is unknown. The above results indicate that as more evaluations are performed, most subjects tended to reach a stable comfort value. However, although the variability is decreased, it can still be debated what in fact is the "true" comfort value. Is it the final rating or an average of several of the last ratings? Probably more importantly from a practical perspective is to determine how many measurements are required until a comfort rating is stable and representative of the overall comfort. Several comparisons were made to determine which group of trials best represented the "true" comfort rating. Average comfort ratings from trials 2-6, 3-6, 4-6, and 5-6 were calculated to represent different possibilities for "true" comfort. The "true" comfort rating was calculated using all of the assessments available for those sessions. For example, the "true" rating for sessions 2-6 was calculated from 15 data points for the control insert and five data points for the other inserts. Comfort ratings for different combinations of trials were then compared to these averages to determine which combination resulted in the smallest difference from the average (Figure 11). For the control insert, the different combinations were calculated using only the first assessment of each set. For example, the comfort rating for the control insert for sessions 2-6 was calculated from 5 data points. This was done to ensure a consistent weighting of each insert in the comfort comparisons but lead to small non-zero differences in the comfort ratings for the same sessions

Difference in Comfort Ratings

2.00

Sessions 2-6

1.50

1.00

0.50

0.00

2/3

2/4

2/5

2/6

3/4

3/5

3/6

4/5

4/6

5/6

6

Sessions

Difference in Comfort Ratings

2.00

Sessions 3-6

1.50

1.00

0.50

0.00

2/3

2/4

2/5

2/6

3/4

3/5

3/6

4/5

4/6

5/6

6

Sessions

Difference in Comfort Ratings

2.00

Sessions 4-6

1.50

1.00

0.50

0.00

2/3 2/4 2/5 2/6 3/4 3/5 3/6 4/5 4/6 5/6 6

Sessions

Difference in Comfort Ratings

2.00

Sessions 5-6

1.50

1.00

0.50

0.00

2/3 2/4 2/5 2/6 3/4 3/5 3/6 4/5 4/6 5/6 6

Sessions

Figure 11. Average difference in comfort points compared to the average of comfort ratings calculated for sessions 2-6, 3-6, 4-6 and 5-6.

The results indicated that the smallest difference occurred for comfort values calculated using trials 3-6 or trials 4-6. In both cases the difference in comfort rating was below 0.40 comfort points and averaged about 0.25 comfort points. Even though it is unknown what the "true" comfort assessment is, by taking the mean comfort rating from either trials 3-6 or 4-6 it appears that the average maximum error will be 0.4 comfort points. On a 15-point scale, an error of 0.4 points is very small representing less than 3%. Mündermann et al. (in press) came to a similar conclusion and recommended averaging comfort ratings from trials 4-6 to obtain an accurate comfort rating. Even though they collected ten repeat measurements, they did not find any improvement by including additional latter trials. It is therefore recommended to calculate the average of trials 3-6 for the "true" short-term comfort. This method was applied for short-term comfort calculations for further analysis in this investigation.

Long-Term Comfort

To assess long-term comfort, subjects were required to wear an insert for a minimum of five consecutive hours on two consecutive days before returning to the lab to rate the insert. Upon returning, they again followed a repetitive protocol with a baseline insert. However, since the subject was now familiar with the insert, only three repeat assessments were performed. Since the first assessment was found to be highly variable in the short-term ratings, it was not included in the calculations of the long-term comfort. Thus, long-term comfort was calculated by averaging the comfort ratings from trials 2 and 3. There were no significant differences between the average short-term and long-term comfort ratings for any of the inserts (Figure 12). This was independent of whether the short-term rating was calculated using trials 3-6 or 4-6. The largest difference was only 0.57 comfort points and occurred for the hard insert. Thus, it appears that the short-term comfort ratings well represented the longer-term comfort ratings.

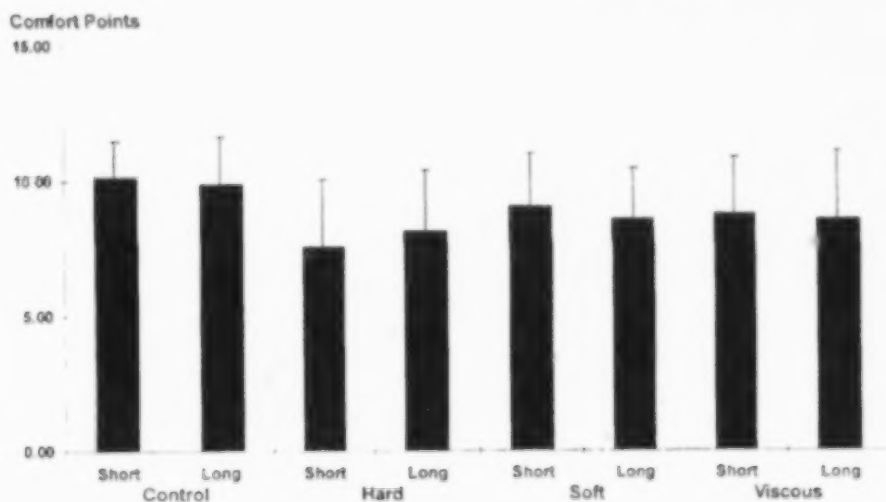


Figure 12. Average short-term and long-term comfort ratings for the four different insert conditions.

When comparing all subjects and all inserts, there was a strong correlation ($R = 0.71$) between short-term and long-term comfort ratings (Figure 13). Thus, after wearing the inserts for a couple of days, most subjects gave the inserts ratings similar to their short-term ratings. The correlation between short-term and long-term comfort rating is improved by removing the five subjects who were found to be less repeatable in their short-term comfort ratings (Figure 14). When comparing the comfort ratings for the 17 repeatable subjects, the correlation between short-term and long-term comfort increased to $R = 0.885$. Overall, the short-term comfort ratings appear to well represent long-term comfort.

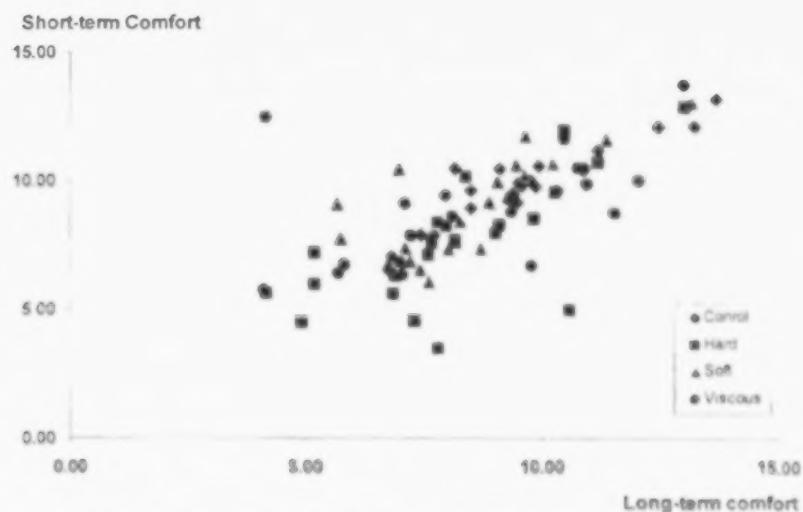


Figure 13. Correlation between short-term and long-term comfort ratings for all 22 subjects.

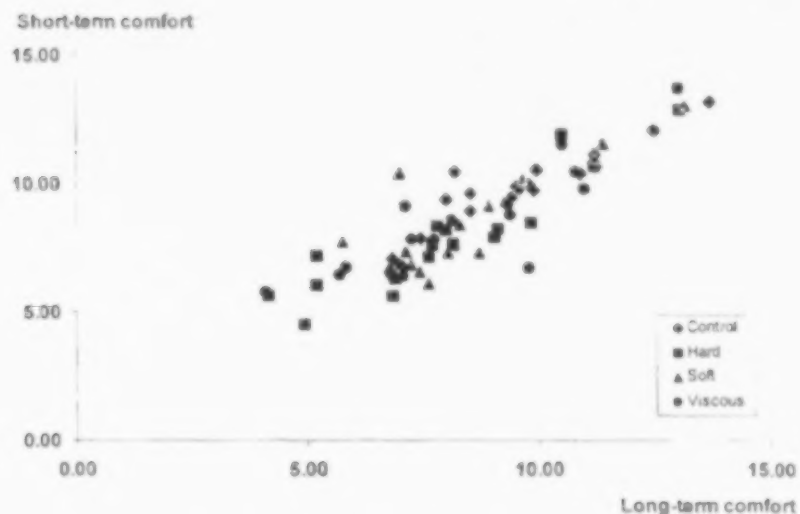


Figure 14. Correlation between short-term and long-term comfort ratings for the 17 repeatable subjects.

EMG

EMG patterns for the lower extremity muscles (Figure 15) were representative of the general patterns for walking published in the literature (Winter et al., 1987). The primary role of the biceps femoris (hamstrings) is to flex the knee. Thus, it was active during the end of swing to flex the knee before ground contact. The primary role of the rectus femoris (quadriceps) is to

extend the knee. It is predominantly active during the first half of stance to prevent the knee from flexing excessively during the loading phase. The primary role of the gastrocnemius medialis (calf muscle) is to plantarflex the ankle (point the foot downward). It is mainly active during the last half of the stance phase to push-off and propel the body forward. The primary role of the tibialis anterior is to dorsiflex the ankle (point the foot upward). It is active just prior to and during the first part of the stance phase to lift the toes during touchdown. The primary role of the peroneus longus is to stabilize the ankle and evert the foot with respect to the lower leg (rotate the foot to the outside of the body). It is active throughout the stance phase to help stabilize the ankle while the foot is in contact with the ground.

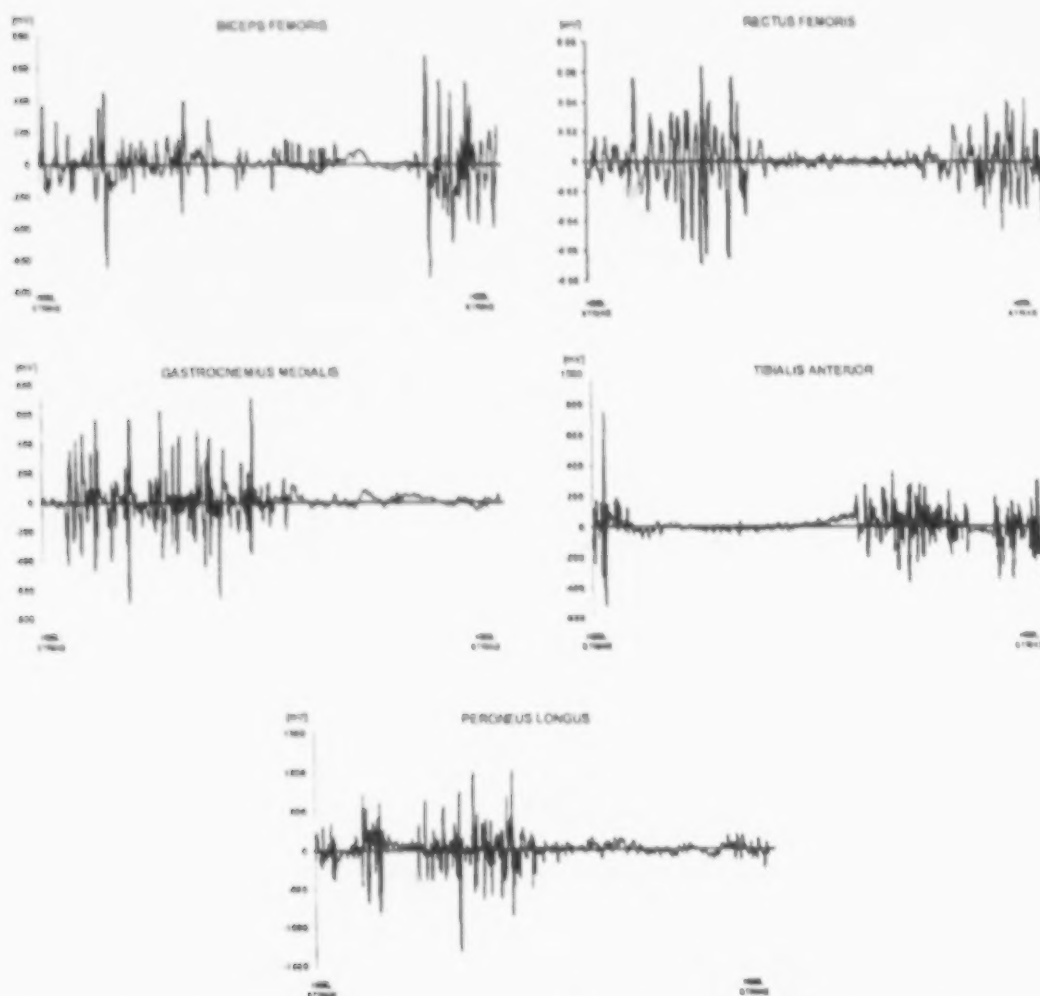


Figure 15. Sample raw EMG patterns of the five muscles quantified in this investigation. The data presented are single trials for a subject while walking with the control condition.

Subject specific differences existed in EMG timing, frequency and intensity.

- ⇒ Some subjects showed earlier onsets and longer durations of muscle activity than others. The differences were substantial.
- ⇒ Some subjects showed changes in EMG intensity when changing between different insert conditions while others did not (Figure 16).
- ⇒ Some subjects showed changes in the mean frequency of the EMG signals when changing between different insert conditions while others did not (Figure 17).
- ⇒ The differences in EMG intensities and EMG mean frequencies were rather small.

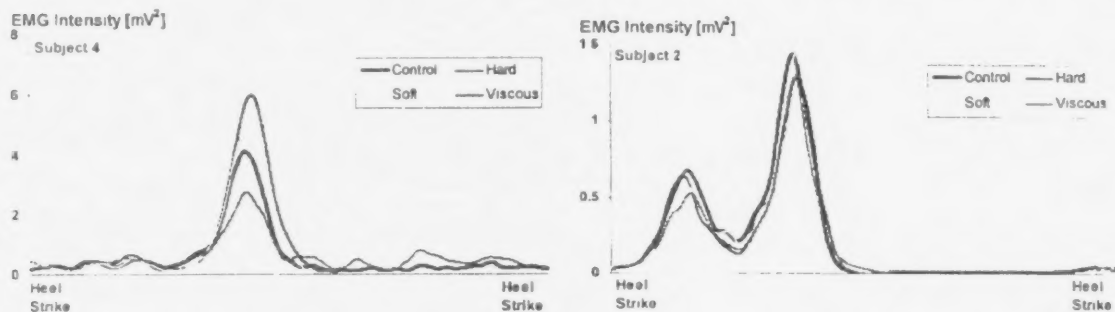


Figure 16. Average EMG intensity of the gastrocnemius medialis for one subject who did (subject 4) and one subject who did not (subject 2) show changes between different inserts.

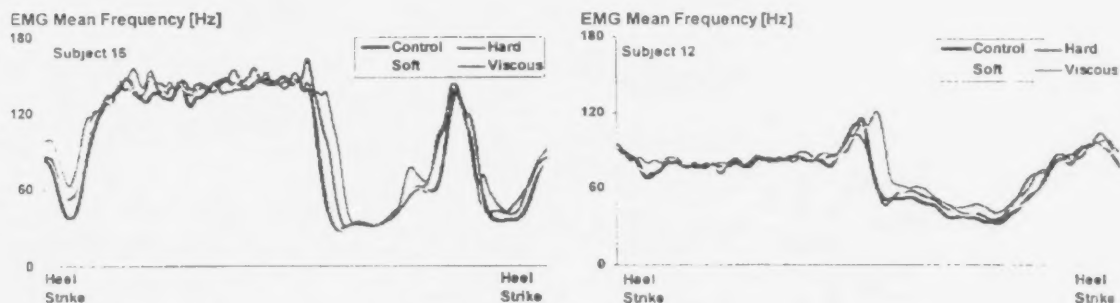


Figure 17. Average EMG frequency of the gastrocnemius medialis for one subject who did (subject 16) and one subject who did not (subject 12) show changes between different inserts.

EMG activity during locomotion is influenced first and foremost by the task at hand (in this case walking), second by the footwear (in this case a standard running shoe, Adidas Hoshi), third by the surface (in this case a treadmill), fourth by shoe inserts and fifth by other external factors (e.g. temperature). Furthermore, changes in EMG activity should be expected if the inserts affect the path of motion of the skeleton substantially (which they probably did not do) or if the impact forces produce resonance effects in soft tissue vibrations (which is not likely during walking).

In this study, the tested inserts were rather similar. Thus, changes in muscle activity and the corresponding EMG signals should be expected to be small and the results should not be a surprise. The small and inconsistent changes in EMG pattern suggest that an assessment of EMG activity may not be appropriate for assessing the functionality of inserts/orthotics/shoes with small changes.

EMG and Comfort

There were no consistent differences in the EMG patterns between comfortable and uncomfortable inserts. Some subjects had increased EMG intensity while walking in shoes they rated as more comfortable while others had increased activity with shoes they rated as less comfortable. Thus, on average, there were no significant differences between muscle activity for the different comfort ratings (Figure 18).

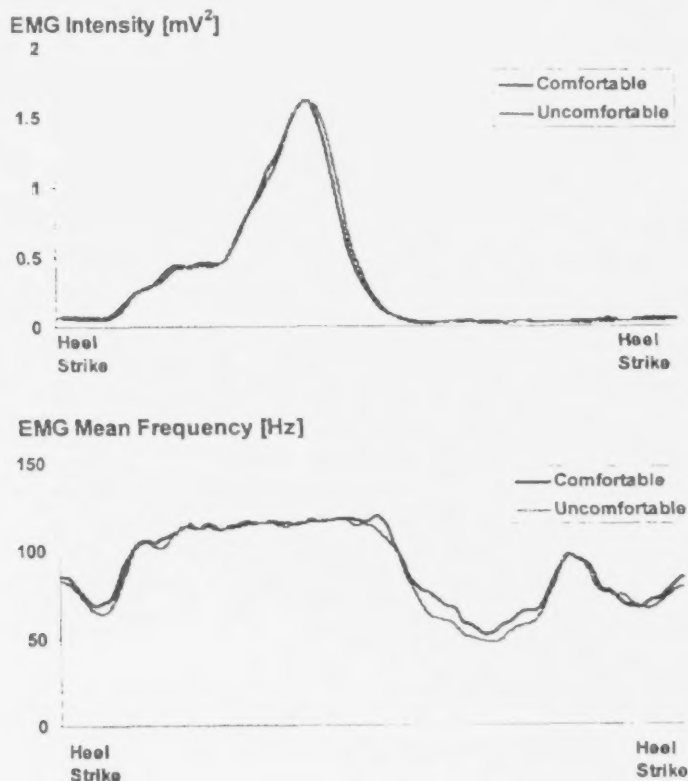


Figure 18. EMG intensity and frequency of the gastrocnemius medialis. The data presented are averages of the comfortable condition (dark line) compared to the uncomfortable condition (light line). The comfortable inserts were rated a minimum of two comfort points higher than the uncomfortable inserts. Data were similar for the other muscles tested.

Initially it was speculated that discomfort would be associated with extra EMG activity that is not related to the task at hand (e.g. walking). Subjective comfort was speculated to be high when extra EMG activity was minimal and low when extra EMG activity was high (Figure 19). The graph shows an increase in EMG activation prior to heel strike (anticipatory EMG activity) for the uncomfortable shoe. It has been proposed that this increased EMG activity may be required to minimize possible vibrations of the calf muscles that might be initiated through the impact shock. During the latter half of the stance phase, the uncomfortable shoe may force the subject into an inappropriate movement pattern. Therefore, muscle activation would be required because the runner has to counteract the changes to maintain or to return to an optimal movement pattern. The fact that these effects were not seen may be explained in the same way as was argued in the general EMG section:

The differences in the inserts were not large enough to produce changes in the skeletal movement path and/or to change the frequency content of the input signals to elicit changes in the muscle activity patterns. Although some subjects were able to perceive differences in the comfort of the different inserts, the changes may have been too small to influence the movement pattern or the muscle activation. The inserts are only approximately 5 mm thick and it could be argued that differences in material properties for this small a thickness will not influence gait patterns. However, it is not surprising that comfort was influenced because the insert is in direct contact with the plantar surface of the foot. The speculation relating to extra muscle activity for uncomfortable footwear should be tested further with larger material differences, for example changes within a shoe midsole, before it is dismissed.

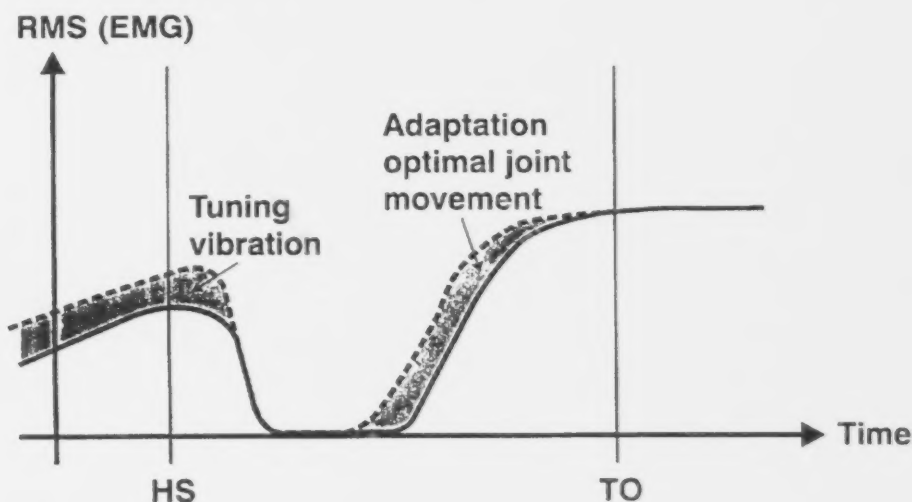


Figure 19. Schematic illustration of the concept that extra muscle activity that is not needed for the task at hand might affect the subjective comfort assessment. The vertical axis depicts the root mean square (RMS) of the electromyography signal for the calf muscles during a running stride. HS represents heel strike and TO represents toe-off. Solid line: muscle activity with a comfortable shoe. Dashed line: muscle activity with an uncomfortable shoe.

It appears that EMG measurements cannot be used to assign inserts to individuals. However, the fact that the EMG did not change dramatically when using the different inserts could be seen as a positive result for the military. This result suggests that manipulating the insert materials will not affect muscle activation dramatically. Therefore, potential negative effects of changing inserts on muscle activation are not a concern. This may also explain the previous results, that there were no differences in oxygen consumption when using the different inserts during the second phase of this investigation.

SUMMARY

Subjects are able to identify comfort differences in different footwear inserts. Furthermore, short-term footwear comfort can be repeatably assessed within 0.5 comfort points by using the appropriate methodology. By having subjects perform six repeat trials and then averaging the ratings from trials 3-6, repeatable and reliable comfort ratings for footwear inserts were obtained. Using this methodology, the short-term comfort ratings were also highly correlated to long-term comfort assessments. Some subjects were less repeatable than others, which does not influence individual comfort ratings. However, it is recommended to remove the assessments from unrepeatable subjects if an average comfort rating for particular footwear is required.

Changes in inserts produced no consistent effects with respect to muscle activity. The majority of subjects showed no changes in mean EMG frequency and/or intensity as a function of changes in inserts. However, some subjects showed changes in the EMG output. Changes in muscle activity were expected when the inserts attempted to change the path of motion. However, these changes may have been small and the tested inserts may all have been acceptable, providing only small differences in functional responses. Thus, assessment of EMG activity may not be appropriate for assessing the functionality of inserts/orthotics/shoes with small changes.

Based on the results of this study one can conclude that comfort assessment is the best approach in selecting an adequate footwear condition. It is repeatable, not time consuming and (based on results from previous studies) seems to be related to functional aspects.

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DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY Human Performance Lab, University of Calgary, Calgary, Alberta		2. SECURITY CLASSIFICATION UNCLASSIFIED Unlimited distribution -
1b. PUBLISHING AGENCY DRDC Toronto		
3. TITLE (U) Short-term and long-term comfort and EMG associated with shoe inserts		
4. AUTHORS Darren J. Stefanyshyn, Antra I. Rozitis, Benno M. Nigg, Prothromo Stergio		
5. DATE OF PUBLICATION June 1 , 2002	6. NO. OF PAGES 28	
7. DESCRIPTIVE NOTES		
8. SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY Sponsoring Agency: Monitoring Agency: Contracting Agency : Tasking Agency: DRDC Toronto		
9. ORIGINATORS DOCUMENT NO. Contract Report CR 2002-053	10. CONTRACT GRANT AND/OR PROJECT NO. W7711-007680/001/TOR	11. OTHER DOCUMENT NOS.
12. DOCUMENT RELEASABILITY Unlimited distribution		
13. DOCUMENT ANNOUNCEMENT Unlimited announcement		

14. ABSTRACT

(U) It was previously determined that military personnel would be more comfortable and suffer fewer injuries by using footwear inserts in their combat boots. However, different individuals require inserts with different characteristics. Since improved comfort is one of the main benefits of an appropriate insert, the goal of this study was to develop a simple comfort assessment method that would allow individuals to select the insert that was appropriate for them. By using a combination of short-term and long-term comfort assessments, a method was developed where subjects could reliably select the appropriate insert. To do this, subjects are required to assess the comfort of each available insert six times while trying them on in a random order. Their most comfortable insert in trials 3-6 will remain the most comfortable for them even after long-term wear, and is, therefore, the appropriate insert for them.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Footwear; boots; inserts; comfort; EMG; CF